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Music and Mathematics: Key Components and Contributions of an Integrated STEAM Teaching Approach

The limited number of STEAM educational experiences in Spain was the motivation behind this study, whose goal was to identify the contributions and essential components of integrated STEAM teaching, specifically the approach that relates the arts (music) to science subjects (mathematics). To this end, a multiple case study was carried out in primary classrooms at three schools. The interviews carried out with teachers, students and management teams, and the observation of the application of different activities provided a comprehensive vision of the keys to integrated STEAM teaching (co-teaching, coordination and an interdisciplinary relationship between subjects). The data also brought to light the benefits of STEAM educational practice (procedural mimesis between subjects, student motivation, links between teachers, and professional growth) and also the difficulties encountered. All this, contrasted with the ideas expounded in the literature, enables us to propose lines of work that the educational community should find suggestive and inspiring since the combination of science with the arts, creativity, integration and innovation has the potential to promote the necessary aptitudes for students in the 21st century.

Keywords: STEAM teaching; primary education; interdisciplinarity; music; mathematics.

Introduction

Although there is no clear consensus about the definition of STEM¹ (Science, Technology, Engineering and Mathematics) education, nor about what it means in terms of curriculum or how it can be implemented in the classroom (Holmlund, Lesseig & Slavit, 2018; Kelley & Knowles, 2016), STEM education can be understood as seeking to promote the scientific-technological vocations and an education that provides scientifically and technologically competent citizenship, generating attitudes towards science and technology that have no socio-economic or gender bias (NAE & NCR, 2016; OECD, 2008, 2018).

The addition of Arts (A) to the STEM acronym offers students the opportunity to illustrate STEM concepts creatively and imaginatively (Quingley, Hero & Jamil, 2017; Sanz-

¹ Note to the reader: throughout the article the initials in the acronyms (STEM or STEAM) are used as in the referenced literature.

Camarero, Ortiz-Revilla, Greca, 2023). They are encouraged to express ideas about the world through music and dance, communicate in descriptive language, capture concepts with crayons or marker pens, draw up graphs and build models (Sharapan, 2012). The arts contribute to creativity (Burnard, 2007; An and Youn, 2018), an essential component of innovation (Ceschini, 2014). However, this incorporation also poses new and serious challenges in the classroom, as it requires the integration of arts subjects that are often seen and used by primary school teachers as a mere resource for learning other subjects (Özenç-Ira & Gültekin, 2022). This prompts a need to review how the integration of STEAM (Science, Technology, Engineering, Arts and Mathematics) education is carried out, in order to ensure that the arts are taught on a par with science, technology, engineering and mathematics.

There are various reasons why the arts are considered an instrument at the service of the other subjects, and one of them is that, in the case of many teachers, the arts were not part of their education as students (LaJevic, 2013). This circumstance calls for a review of STEAM education among pre-service and in-service teachers, and for a greater presence in the literature of research that presents and analyses STEAM integration in primary classrooms, given that there is a lack of empirical studies that examine how to implement the STEAM framework in real classroom contexts or explain how to carry out effective STEAM teaching (Quingley, Hero & Jamil, 2017).

This is the context of this study, whose main goal was to identify essential components of what is understood (as explained later) by integrated STEAM teaching (Sanders, 2009), through learning experiences in different schools that brought together two subjects: mathematics and music. We present a study carried out in primary classrooms, where both subjects were worked on from a joint perspective, fostering students' and teachers' creativity as a means of promoting a more interdisciplinary approach to the teaching and learning process. In the present research, interdisciplinary is understood in the way it is viewed by Lenoir (2013); thus, interdisciplinary designates the effective interactions woven between two or more disciplines and their concepts, their methodological procedures, techniques, etc. Therefore, it is not compatible with any cumulative perspective because it imposes real interactions.

Drawing on proposals aimed at avoiding compartmentalization, we explain how educational contexts can be created to do work based on experiences, activities and materials that promote not only creativity and reflection but also an integrated understanding of the various subjects. In short, fostering proposals that facilitate a more realistic approach to the world we live in provides students with competences that STEAM education promotes.

Theoretical Framework

From STEM Education to Integrated STEAM Education: Notes on the Evolution of an Acronym

Interest in STEM education in the educational world is not new. The idea of STEM education – known as SMET until the early 2000s - began to receive attention in the USA in the 1990s (Kelley & Knowles, 2016), when the National Science Foundation (NSF) adopted it to refer to four disciplines: *Science, Mathematics, Engineering and Technology*. The goal was to make United States students more competitive in these four branches of learning, ultimately taking the Program for International Student Assessment (PISA) as a yardstick (Jamil, Linder & Stegelin, 2018). For over two decades, the NSF used the acronym STEM as an umbrella term for four separate disciplines, for four distinct fields of knowledge, and not from the perspective of integrated education (Sanders, 2009).

Initially, the world's leading economic, political and educational organizations supported STEM-focused teaching not only as a means of improving academic rigor in schools but also because it enabled students to obtain skills and knowledge that have become more and more necessary in the changing world of work. The purpose of introducing STEM into the classroom did not seem to be so much a matter of increasing the number of scientists, engineers and mathematicians but rather of training people to cope with a highly technological world based on many different disciplines (Quingley, Herro, & Jamil, 2017). Currently, STEM education includes activities at all learning levels, from preschool to postdoctoral, and in both formal and informal education (DeJarnette, 2018; Leung & Pang, 2018; Holmlund, 2018).

Then, in 2007, “STEM education” was renamed “integrated STEM education” (Blackley & Howell, 2015). Integrated STEM education includes methodologies that explore learning and teaching involving two or more STEM subjects or branches of learning, and/or involving a STEM subject and one or more school subjects (Sanders, 2009). Instead of teaching content and then expecting students to see the connections, it is an approach that builds on the connections between subjects to provide a relevant context for learning the content (Kelley & Knowles, 2016). It is an approach that provides a more logical way of implementing STEM in schools (Blackely & Howell, 2015).

For some authors, STEM education appears to refer to a methodology that encourages students to explore and solve problems related to the world around them. In this context, the activities carried out in the classroom are expected to replicate real life. It is also conceptualized as a transdisciplinary learning process that tackles different content areas conjointly (Quigley,

Herro, & Jamil, 2017).

Subsequently, the STEM acronym evolved into STEAM on incorporating the Arts (A), where the letter A can refer to the performing arts (music, dance, etc.), fine arts (painting, sculpture, etc.), body expression, the humanities, and so on. The meeting of the arts and STEM subjects not only enhances student engagement and learning but also helps unlock creative thinking and innovation (Sousa & Pilecki, 2018). Supporting this idea, Jamil, Linder and Stegelin (2018) stated that productivity and prosperity in the world of work depend on the innovative capacity in technology and the arts, complemented by a solid understanding of science, engineering and mathematics.

Music and Mathematics, a Binomial for Integrated STEAM Education

As advocated by Sanders (2009), STEAM education should focus on the relationship between a maximum of two disciplines to optimize work in the classroom, and this is precisely what is meant by integrated STEAM. The intentions of STEAM are reflected in learning music and mathematics together, for example. Mathematics and music, as well as being subjects with close ties, have been and continue to be an integral characteristic of all cultures (Shah, 2010). Authors such as Roberts (2016) have discussed the relationship between the two, studying and highlighting their broad common base.

The relationship between music and mathematics goes beyond their connections (Hallam & Himonides, 2022). On the one hand, there are studies that show that music training has a positive impact both on students' mathematical abilities (An, Capraro & Tillman, 2013; Sanders, 2009) and on the results they obtain in mathematical tests (Still & Bovis, 2005). And on the other hand, there are studies that show how mathematics is inherent to music theory (Bhat et al, 2015). Be that as it may, there is little discussion of the role of mathematics in teaching and learning music. From this standpoint, the connections between music and mathematics offer an opportunity to take an integrated approach to working on both subjects in the primary classroom. This integrated approach to teaching is considered beneficial for students because it establishes links between content areas that help them develop a greater understanding of the concepts inherent to the two disciplines (Still & Bobis, 2005). Integrated teaching not only seeks to work on content by interrelating it but also endeavours to work on the acquisition of competences. Furthermore, as stated by Still and Bobis (2005), an integrated approach to teaching mathematics and music also benefits students in the way that concepts

and facts are generally presented in context, as demanded by the principles of integrated STEAM education.

Integrated STEAM Education: a Challenge for Teachers

As affirmed by Novak and Wisdow (2018), if as a society we want students to take an interest in STEAM subjects, it is essential that teachers provide them with meaningful STEAM experiences that motivate them to explore and persevere in the fields of STEAM. Consequently, there is a need to analyze, review and rethink teacher training in order to produce teachers capable of imparting integrated STEAM coursework (Leung & Pang, 2018). Little research has been carried out on how to effectively prepare future teachers to work in STEM or STEAM classrooms, which shows that professional training for teachers in this field has not yet been well defined or studied in detail (Rinke, Gladstone-Brown, Ryan & Cappiello, 2016). A good grasp of the STEM or STEAM subjects is important at primary school level, but, paradoxically, many pre-school and primary teachers have little prior knowledge of these disciplines, unlike in secondary education (DeJarnette, 2018). This makes them less confident and effective when teaching STEM, as they may feel daunted, lack self-esteem and have a negative attitude to this type of education (Jamil, Linder, & Stegeline, 2018). Consequently, these teachers tend to devote less time in their classrooms to STEAM education (DeJarnette, 2018), which can be an obstacle to this type of learning among their students.

Similarly, while primary education offers an ideal learning environment with flexible time slots for integrated learning, learning scenarios are not set up for STEM because many teachers lack the content knowledge needed to do so (Russo, Hecht, Burghardt, Hacker & Saxman, 2011). Moreover, there is currently a demand for a type of teacher education that takes into account the need for schools to integrate the study of different subjects within the framework of integrated STEAM education (DeJarnette, 2018). However, the fact is that most student teachers pursue training courses in which they tackle specific content but rarely learn how to work on it conjointly (Bennet & Ruchti, 2014).

Ultimately, there is another problem. If we consider STEM education as a meta-discipline that integrates content from all STEM fields, it turns out that there are not many teachers who are experts in each and every one of these subjects. Therefore, bridging these individual domains can be an important challenge for teachers (Bennett & Ruchti, 2014). According to Rinke, Gladstone-Brown, Ryan and Cappiello (2016) a good STEM education not only depends on the integration of the content. Rather, teachers must also be able to take

an innovative approach that implies a command of what they denominate the “STEM literacies”, with the acquisition of the skills needed to cope with challenges of the 21st century, such as adaptability, the solution of non-routine problems, self-management, and self-development. Thus, an integrated STEM approach requires teachers with good generalist (holistic) knowledge and, in turn, with a good conceptual, procedural and epistemological understanding of the different subjects (Bogdan Toma & García-Carmona, 2021).

Methodology

The goal of this study was to determine how integrated STEAM teaching can be introduced into primary school classrooms and ascertain its contributions to integrated education. We present a multiple case study (Stake, 2005) because the observation of different contexts allowed us to identify and elucidate on the essential components of integrated STEAM teaching, specifically in relation to the fields of mathematics and music. We decided it was necessary to explore the entire process, from the preparation of the activities to their implementation in the classroom, and also to verify the impact it had on students and know the opinions of teachers and school management teams.

Participants

The study was carried out in three schools in the province of Barcelona (Spain). The sample was chosen intentionally (Riba, 2015) taking into account the accessibility of the centres and their varying characteristics (Table 1) in order to cover a different context of STEAM activities application and being able to get richer and complete data. In this research, the application of three integrated STEAM activities involving music and mathematics was observed in five class groups pursuing primary education. Three members of different management teams, twelve students of different ages, and six teachers were interviewed (Table 1). All the participating teachers had previous training and experience in the implementation of activities that relate music to mathematics and so they understood what integrated STEAM teaching implies and knew what types of activities could be carried out.

Table1. Sample characteristics.

	School 1	School 2	School 3
Location	Town	City	Village

Category of school	State-run	Public-private partnership	State-run
Students demographic characteristics	High immigration and low socioeconomic family status.	Low immigration and medium socioeconomic family status.	Low immigration and medium socioeconomic family status.
Age of students involved in the activity	11-12 year olds	7-8 year olds and 9-10 year olds	10-11 year olds and 11-12 year olds
Member of management team interviewed	Head of studies	Director	Director
Students interviewed	Two 11-12 year olds	Two 7-8 year olds Two 9-10 year olds	Two 10-11 year olds Two 11-12 year olds
Participating teachers	1 class teacher 1 music teacher	1 class and music teacher 1 music teacher	1 class teacher 1 music teacher

Research Design and Data Collection

The procedure and data collection can be grouped into three large blocks:

Activities' Design. First of all, it was necessary for the teachers participating in the activity to devise activities that combine music and mathematics. In parallel, the researchers planned and designed data collection techniques and instruments. The activities were prepared by the teachers at each school and validated by the Musicomàtics teacher work group (see Note 1), seeking, as in the choice of schools, a wide variety of scenarios according to the multiple case study methodology. Each activity tackled different musical and mathematical content (see Note 2) and was applied at different primary education levels (Table 2). Using the non-participant observation technique, one of the researchers attended six sessions to prepare content (a one-hour meeting at *School 1*; three 20-minute meetings at *School 2*; and two meetings lasting one hour and 30 minutes respectively at *School 3*) and/or the activity that was going to be implemented in the classroom. The researcher took field notes during these sessions.

Table 2. Music and mathematics activities carried out in each school.

	School 1	School 2	School 3
Name of activity	Body movement and fractions.	Body percussion and number decomposition.	The dance <i>Violet Saint Pere</i> and axes of symmetry.
Goal of activity	Work on the importance of the unit in both mathematical fractions and musical figures.	Understanding and practicing number decomposition, recognizing and performing different sounds with the body.	First-hand experience of spatial distribution by following the steps of a dance (music and mathematics).
Length of activity	Five 1-hour sessions	Three 1-hour sessions	Eight 30-minute sessions
Description of activity	Through physical experimentation, students look for different ways to represent each musical figure with their bodies, with special emphasis on their relationship according to the unit.	A rhythmic task of body percussion performance and recognition carried out while multiplying and dividing.	Work on dance steps and, at the same time, on distribution in space and geometric properties (axial symmetry, straight lines).

Activities' Implementation. These activities were carried out at different primary education levels. One of the researchers acted as a non-participating observer. Sixteen class sessions (12 hours) were observed and videotaped, and an observation table prepared for this purpose was used as a data collection tool. The observation table served to evaluate items referring to the organization of the activity (presentation, development, space, timetable, etc.); the students (participation, motivation, interest, etc.); the teachers (coordination, roles, etc.); and the integration of the subjects (balance between content, interdisciplinary relationships, etc.).

Participants' Perceptions. The semi-structured interviews carried out with the students, the management teams and the teachers all had the same layout, although, depending on the group involved, some aspects or others were explored in greater detail during each interview. The questions were intended to obtain information about the following:

- Their opinion of STEAM teaching when it relates music and mathematics in an interdisciplinary way (importance, benefits to students, previous experiences, expectations, etc.).
- Their perception of how STEAM teaching functions when it relates music and mathematics (organization, implementation, teacher coordination, session preparation, creation of activities, etc.).
- Their assessment of STEAM music and mathematics teaching (advantages, disadvantages, difficulties, benefits, changes, contributions, etc.).

All the interviews were audio recorded.

Data Analysis Process

Once we gathered and collected the data, prior to its analysis, we organized it using the qualitative data analysis software Nvivo. Analytical categories and subcategories (Table 3) were then established deductively on the basis of the items in the interviews and observation tables. This process was repeated for each of the cases that make up this research. Finally, we used data triangulation (connecting the data collected in the non observation procedure of the activities, the analysis of the activities, the interviews with different participants and the field notes of the researcher) to obtain a global vision of the implementation of integrated STEAM teaching, specifying some of the keys to STEAM teaching and paving the way for further possible activities.

Table 3: Analytical categories

Category	Subcategory
Characteristics of integrated STEAM teaching	Co-teaching (models)
	Teacher organization and coordination (space, timetable, teaching difficulties, logistical changes).
	Music and mathematics (interdisciplinary content, subject relationship).
	Student competencies
Implications of integrated STEAM teaching	Contributions of STEAM (from A to M; from M to A).
	Balance between music and mathematics

	Student implications (students' opinions, learning outcomes)
	Teaching implications (teachers' opinions, changes in teaching practice).

Results and Discussion

Key Aspects of Integrated STEAM Teaching in Primary School Classrooms

The activities designed for this research were based on integrated STEAM teaching. Following the ideas of Sanders (2009), it combined just two subjects: music and mathematics. The results show the implications of bringing together two subjects with different profiles, one more artistic and the other more technical.

Use of Co-teaching to Foster Effective STEAM Learning. It was observed that when carrying out activities that relate music and mathematics in the classroom, the teachers organized the classes in different ways. All the schools in the study opted for co-teaching (Gately & Gately, 2001) involving a music teacher and a class teacher. Co-teaching was chosen in view of the fact that it is not easy for teachers to have a good command of all the content (Bennet & Ruchti, 2014), which becomes a greater difficulty in the case of music, where it is necessary to master the specialized musical skills and knowledge in order to teach it. In this sense, Russo, Hecht, Burghardt, Hacker and Saxman (2011) argue that when a single teacher lacks the knowledge and content necessary to create STEAM learning scenarios, co-teaching provides a positive approach because it means that teachers become familiar with and learn content that they are not used to dealing with.

The co-teaching models used were different in each school due to the nature of each activity and the teacher possibilities and needs. During the evolution of the sessions we observed that both teachers were always present in the classroom in *School_1*, although each one was responsible for the part of the content that they knew best: mathematics or music. According to Suárez-Díaz (2016) this is an example of a *parallel teaching* model, since the teachers shared their knowledge, but each one directed a part of the teaching. In *School_2*, the teachers were present in the classroom at the same time but took advantage of the fact that they were both music specialists to lead the sessions interchangeably. This is an example of a *team-teaching* model (Suárez-Díaz, 2016) since the teachers, apart from sharing their knowledge,

intervened interchangeably during the sessions. A good command of the content of both subjects facilitates this teaching model:

“Both of us were always in the classroom and we worked on the two subjects without distinction, both music and mathematics. The particularity is that I’m a music teacher by training and therefore it was not a problem for me to teach music.” (Class teacher *School_2*)

In *School_3* the teachers divided the students into two groups, each one being responsible for one group, and later they exchanged groups. This is a case of working in small groups on a rotational basis and is therefore an example of a *station teaching* model (Suárez-Díaz, 2016), since the two teachers work separately with both the groups and the tasks to be carried out.

This research showed that co-teaching is an optimal choice for STEAM teaching since the possible gaps in teachers’ knowledge can be plugged. The chosen teaching model will depend on the teachers’ knowledge of the subject and the possibilities of the timetable and available space in the school.

Demand on Teachers’ Time and Need for Coordination to Prepare and Develop STEAM Activities. When teachers choose to tackle STEAM activities using co-teaching methods, the coordination between them plays a key role in the proper development of this type of activity and in ensuring the students understand the content. There is scope for coordination prior to and during the activities, and it has different functions: preparing the activities together, making decisions on how to continue, distributing the content to be worked on, sharing knowledge and training. It generally takes place outside school hours due to the shortage of time in work hours:

“We do almost everything outside because preparing this type of activity requires a lot of time to think, because the two subjects must be carefully linked up. We don't have enough time to do this preparation at school.” (Teachers *School_3*)

The teachers’ comments indicate that STEAM activities can be somewhat demanding and problematic, since the content must be precisely connected to provide a relevant context for their development (Kelley & Knowles, 2016).

In general, schools are not prepared for this type of teaching practice and this is an additional difficulty for those teachers who decide to break the mold and dare to modify methodologies and innovate, since it implies extra work outside school hours (Schleicher, 2015). We realize that the timetables were not planned to enable two teachers to work together

in the classroom and so the progress of the STEAM activities depended instead on the teachers' willingness and dedication. There were management teams that were aware of the implications and demands of this type of activity:

"It is obvious that STEAM activities require logistical changes (organization of teachers, students, timetables...) and also training for the teachers involved." (Management team *School_2*)

However, they also commented that it takes a lot of time and effort to introduce these logistical and structural changes, with the onus of responsibility left to the teachers.

Use of Interdisciplinary Models to Bring Together the Subjects Involved in STEAM Teaching. The participating teachers were aware that in STEAM activities the relationship between the content of the different subjects must be balanced, by basing it on coordination between the two subjects and not on the subordination of one or the other. As proposed by LaJevic (2013) and Özenç-Ira and Gültekin (2022), the intention was that the arts should not be treated as an instrument at the service of mathematics. However, it was difficult to achieve this in view of the existing school tradition and the different relevance that has been given to each of the subjects:

"In the activities we sometimes observed that music ended up being a medium for teaching mathematics. There was a lack of balance between the two subjects." (Teachers *School_1*)

The research revealed that the planning, creation and preparation of well-balanced activities is very demanding:

"These types of activities cannot be put into practice and left to run their course just like that; they must be constantly reviewed, and redirected in the event that one of the subjects falls behind the other. They are demanding activities, not only as regards their implementation but also their preparation". (Teachers *School_2*)

We observed that the teachers' efforts paid off when it came to ensuring a balance between the two subjects taught in the activities. Furthermore, this shows that the aforementioned coordination can lead to different types of interdisciplinary relationships. Drawing on the method of classification proposed by the Russell-Bowie (2009), three types of relationships between the two subjects were observed in this study, all of them to a greater or lesser extent valid for STEAM teaching:

- Interdisciplinary relationships through *syntegration*: the two subjects function together to look for synergies in order to understand aspects that they have in common. Authentic integrated learning takes place within this interdisciplinary relationship, since the

relationship established between music and mathematics focuses on interaction, cooperation and reciprocity between the contents. For this to occur, the musical and mathematical contents must carry the same weight and the interconnections linking the two subjects must be identified:

“We were decomposing numbers using body percussion. We tapped out the rhythms according to the number that they gave us, and depending on the sound on the body that we heard represented hundreds, tens or ones”. (Student *School_2*)

- Interdisciplinary relationships through *symmetric correlation*: common content is used to achieve the goals of the subjects. Here, working on music and mathematics at the beginning of the activity merely serves as an excuse to split up the two subjects and treat the content separately. It is our understanding that this is the most easily attainable relationship, given the current conditions in most schools in our context. Nonetheless, this approach diverges from the STEAM philosophy, where balance and interconnections must prevail. In the following quote, the student refers to doing mathematics, not music:

“We did maths artistically, we moved.” (Student *School_1*)

- Interdisciplinary relationships through *service connections*: one discipline is used as an excuse to reach the other and vice versa. Points of connection between both areas are guaranteed throughout the development of the activity, thereby enabling the contents to evolve separately until they reach a point where they meet again, without losing sight of the coordination required of STEAM activities. One content item leads to another:

“I really liked dancing the Violet dance and then finding bits of maths in it and then going back to creating a dance.” (Student *School_3*)

Contributions of Integrated STEAM Teaching in Primary School Classrooms

We observed that the "A" contributes a more experimental and creative vision of the world to STEAM teaching, which enables students to communicate in more descriptive language and find different ways to reach the same end. The research results show that there are contributions in both directions when STEAM teaching combines music and mathematics. Thus, we saw how manipulatives, body movements and sound patterns help children to understand the mathematical world, as pointed out by Viñas, Casals and Viladot (2022). In the same way, the

logic and organization of mathematical thinking helps to identify connections in music. In this respect, one of the participating teachers affirmed the following:

“It makes it possible to see the world in a different way. It makes you understand that there are other ways of getting to the same place, that all the paths are viable as long as you reach your destination.” (Teacher *School_1*)

STEAM Teaching Provides a Procedural Mimesis Between Subjects. The data collected shows how combining two apparently very different subjects can promote the emergence of a procedural mimesis (in the sense of imitating or using similar procedures to teach. For example, reflecting more in the case of music or experiencing the activities in the case of mathematics) that breaks down the boundaries separating the subjects and enables them to be taught from another perspective.

On the one hand, we found that work on music contributes practice, movement and creativity to mathematical activities and helps make the abstract tangible because students use their own bodies to experience and express what they are learning.

“I’ve realized that students need to move, to touch things, to be aware of how they can be expressed, and not only in writing. You realize that what you assumed was good enough up till then really needs changing. You see how students need to experiment. If you are working on straight lines, then get them to follow a straight line!” (Class teacher *School_2*).

On the other hand, as different authors stated (Holmes & Hallam, 2017; Sanders, 2009) mathematical thinking helps students to find connections in music and provides many explanations. We could talk about a procedural mimesis that reinforces the acquisition of content and enables students to see the world from different perspectives.

It was also observed that STEAM teaching gives equal value to music and mathematics. In Spain, these two subjects carry different importance on the curriculum and, consequently, in schools. Mathematics is part of most assessment tests (basic skills, PISA, etc.) and therefore takes up more space on the school timetable than music. This research shows how STEAM teaching promotes music at school:

“STEAM teaching is important because it works on the arts and we think this is a way of justifying the work done on music in the school and giving it the value and importance it deserves.” (Management team *School_1*)

STEAM Teaching is Motivating and Meaningful for Students. The analysis of the results showed that combining music and mathematics was a novelty for the students since

they were not used to relating these two subjects. In general, as Kelley & Knowles (2016) could also observe, the students were motivated by STEAM teaching and surprised on discovering the connections. It gave them a more holistic view of reality and they had fun while learning:

“What I liked is that we realized that when we were doing maths we were actually composing scores, because we had to unite the rhythm and the melody and make them coincide.” (Student *School_3*)

STEAM teaching presents content to the students in a different way to what they are used to, closer to the reality they will have to cope with in the future, because learning is not divided up or compartmentalized in the outside world. Rather, each person relates, experiences and seeks resources for his or her own development. As Jia, Zhou & Zheng (2021) states, the results show that STEAM teaching opens students’ minds, which is a point in its favour because it helps to prepare them for their growth in society and obtain the knowledge and skills that are becoming increasingly necessary in the changing world of work. STEAM teaching brings students a little closer to this goal and therefore makes learning truly meaningful and effective: “It’s made me see that it’s not so necessary to keep strictly in line with the curriculum, that it’s possible to take things further and do more useful things, which can serve the children for life and motivate them while they learn.” (Teachers *School_3*)

We also observed that the learning outcomes were not the same for all the students because some did not succeed in getting involved in the activities. While it seems that STEAM types of activity are especially interesting for those students who do well in both subjects because they learn to make connections and structure their thinking, they are less useful for students with learning difficulties. We think the explanation lies in the characteristics of the designed activities, more experimental than concrete and possessing a very dynamic character and content connections that are not immediately perceptible. Students’ personal traits may play a part too: shyness, lack of experience with expressive activities that require them to perform or do things in front of others, etc. Here, the solution might be to plan more continuous STEAM teaching in order to give students more time to internalize the methodological changes and process this type of learning.

STEAM Teaching Creates Links Between Teachers and Improves Their Professional Practice. Although we have commented that coordination between teachers presents some difficulties, the research carried out also shows that co-work generates close

bonds between teachers, which enrich and inspire their teaching practice. It was also observed that carrying out STEAM activities in the classroom fostered the participating teachers' desire to learn, even their lack of confidence on developing the activities (Nadelson et al., 2013), and enabled them to discover the possibilities of working on different subjects and incorporating them into their own field of work:

“Now I want to know more mathematics and also learn more about how to link up the two subjects. It's obvious that they are closely related, but if I knew more mathematics I could raise the level.”

(Music teacher *School 3*)

The teachers commented that STEAM teaching offered a new perspective. They reported that they were able to identify mathematical concepts where before they only saw musical concepts, and vice versa. The teachers became aware of the importance of sharing knowledge and not being boxed in by a single aspect. STEAM teaching not only fosters the need for teacher training but also offers them new teaching methods. It prompts them to reappraise their teaching practice and even modify it, and this is a significant plus for education in general.

Conclusions

Although the acronyms STEM and integrated STEAM are terms with impact in the current educational context, there is not a clear definition and guidelines or key strategies for implementation in the classroom. Once completed this research, we concluded that the key point to implement an integrated STEAM education may well lie in understanding that there are as many contingencies as there are classrooms, that the conditions vary from one subject to another. Therefore, specific methods or steps cannot be established for integrated STEAM education, but rather general guidelines that direct its application and enable students to acquire the skills needed to grow in 21st century society. The fact is that integrated STEAM education functions along these lines, since its benefits include providing skills that go beyond specific classroom scenarios. These are non-routine scenarios, which demand adaptability, social skills, and a strong ability to interconnect thoughts and systems (Rinke, Gladstone-Brown, Ryan, & Cappiello, 2016).

The case studies in this research are derived from the complex realities of three different schools. The results show that integrated STEAM education represents a notable challenge for teachers who do not have a good command of each and every one of the disciplines in the acronym (DeJarnette, 2018). Co-teaching, which can be adapted to the context, could play a

key role in creating STEAM scenarios and overcoming this obstacle. However, as long as teacher education is not focused on giving teachers the knowledge needed to cope with STEAM activities, and permanent training is not organized in this sense, schools will have to set aside space and time for teachers to be able prepare these learning scenarios.

The interdisciplinary model is another key component. It cannot be ignored because it determines whether what Rinke et al. (2016) call the STEAM *literacies* can be acquired, i.e. having an innovative approach and being capable of improvising in 21st century society. To achieve this, it is necessary to develop an interdisciplinary relationship through *syntegration* (Russell-Bowie, 2009), where the two disciplines are placed on an equal footing, thus attaining a balance between the “A” and the other letters of the acronym, as advocated by Sharapan (2012). It is evident that building this relationship is not easy and it could be one of the goals of future STEAM activities. In this sense, if we want a real integrated STEAM teaching, it is necessary to go further and be able to create *syntegrated* activities and analyze them, as well as, to go deeper on topics such as teacher confidence, school organization, and student competences.

With the application of these key components, it is possible to identify the contributions of integrated STEAM teaching when one of the disciplines is artistic (music) and the other is scientific (mathematics). In confirmation of Ceschini (2014), Jamil et al. (2018), and Sharapan (2012), it was observed that the arts provide a more experimental and creative vision of the world, with students using more descriptive language to communicate and finding different ways of reaching the same end. We could observe that STEAM teaching generates a very effective and interesting procedural mimesis between the subjects: music helps to make the abstract tangible, and mathematics sheds light on the musical fact.

Furthermore, it was found that integrated STEAM activities tend to deal with holistic scenarios, closer to the outside world that awaits students in the future, where they will have to link up different fields of knowledge. While these are scenarios that encourage them to learn, time needs to be taken over their implementation because the students have to understand how they function and what their own role is.

The research shows that prepared and motivated teachers are needed for STEAM proposals to be successful: teachers who know how to work together, share, build and improve; interested in learning and making progress; willing to abandon their comfort zones and propose effective practices; and aware of the students’ needs. Nonetheless, the fact is that the literature reveals a reluctance on the part of primary teachers to introduce integrated STEM activities in

their classrooms, either for logistical reasons or due to inadequate training and a lack of confidence when it comes to effectively implementing these proposals (Bennet & Ruchti, 2014; García-Carmona & Cruz-Guzmán, 2016; Murphy & Mancini-Samuelson, 2012). The results show that if co-teaching is organized so that each teacher can contribute with their expertise, this barrier is overcome and the teachers' professional practice is also enhanced.

To sum up, this research identifies some of the strengths, weaknesses and potential of STEAM activities in primary classrooms. It presents three specific cases that, even not being generalized, provide some pointers as to how present-day and future education can cope with the challenges of the 21st century and foment a more adaptable and creative society that takes into account that there is no innovation without creativity.

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2. You can find more information about the activities (main goal, musical and mathematical contents and the description of each session) in the supplemental material.

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